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*ESTABLISHING FUNCTIONAL CLASSES IN A CHIMPANZEE (*PAN TROGLODYTES*) WITH A TWO-ITEM SEQUENTIAL-RESPONDING PROCEDURE*

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A 9-year-old female chimpanzee was trained on a two-item sequential-responding task. Attempts were made with successive-reversal training to establish functional classes. In Experiment 1, the subject was exposed to between-session successive-reversal training in which one of two pairs of stimuli was reversed, and transfer of reversal responding to the other pair was tested with nonreinforcement probe trials. She did not show transfer during the course of reversals. Stimulus control established in the original training was maintained on nonreinforcement probe trials. In Experiment 2, within-session reversals were introduced. She showed transfer from the initially reversed pair to the other. The results were consistent with Vaughan's (1988) results with pigeons on successive discriminations, which indicated the formation of functional classes. In Experiment 3, crossover and wild-card tests were conducted to clarify the stimulus control of sequential responding. The results suggested that the sequential responding was controlled only by the first stimulus of each pair. To establish control by both first and second stimuli, trial-unique stimuli or wild cards were substituted for one of the items of the lists in Experiment 4. Further transfer tests, in which stimuli for the two new pairs appeared, were also given to the subject. She successfully responded to these two merged lists and reversed the order as the result of reversal training.

Key words: functional classes, sequential responding, successive-reversal training, stimulus control, screen touch, chimpanzee

Stimulus class formation has been extensively studied in the conditional discrimination paradigm (Devany, Hayes, & Nelson, 1986; Lazar, Davis-Lang, & Sanchez, 1984; Sidman, 1971; Sidman et al., 1982; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991; Yamamoto & Asano, 1995), since Sidman and Tailby (1982) formulated the three defining features of equivalence relations, that is, reflexivity, symmetry, and transitivity. These features were considered to be testable only in conditional discrimination tasks. According to Sidman, Wynne, Maguire, and Barnes (1989), equivalence classes are "identified when relations among their members meet the three defining features of equivalence relations" (p. 261). However, stimulus class formation is not a phenomenon specific to conditional discriminations. Stimulus class formation is also testable in simple discriminations (de Rose, McIlvane, Dube, Galpin, & Stoddard, 1988; Sidman et al., 1989; Vaughan, 1988), in sequential responding (Green, Sigurdardottir, & Saunders, 1991; Lazar, 1977; Sigurdardottir, Green, & Saunders, 1990; Wulfert & Hayes, 1988), in categorization tasks (Bogartz, 1965; Schaeffer & Ellis, 1970), and in discrimination under respondent contingencies (Honey & Hall, 1988). We can say that the establishment of an equivalence class is a special case of stimulus class formation. A more general type of stimulus class can be described as functional equivalence (Goldiamond, 1966), acquired equivalence (Honey & Hall, 1988; Lawrence, 1949), or functional classes (Sidman et al., 1989). These types of stimulus classes are "identified by their members' common behavioral functions" (Sidman et al., 1989, p. 261). In humans, the stimuli with common stimulus functions established in contexts other than conditional discriminations often form equivalence classes (de Rose et al., 1988; Lazar, 1977; Sigurdardottir et al., 1990).

In nonhuman animals such as pigeons (D'Amato, Salmon, Loukas, & Tomie, 1985; Lipkens, Kop, & Matthijs, 1988; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989), mon-

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keys (D'Amato et al., 1985; Sidman et al., 1982), and chimpanzees (Dugdale & Lowe, 1990; Kojima, 1984; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991; Yamamoto & Asano, 1995), emergence of the three defining features of equivalence relations have not been found with the conditional discrimination paradigm. Vaughan (1988), however, attempted to form functional classes in pigeons using a procedure different from the standard conditional discrimination procedure. He used 40 different photographs of trees, half of which were defined arbitrarily as positive stimuli and the rest were defined as negative stimuli. He trained pigeons to peck a key in the presence of the positive stimuli and not to peck in the presence of the negative stimuli using a multiple schedule. When the discrimination criterion was met, stimulus functions were reversed: The previously positive stimuli were changed to negative, and the previously negative stimuli were positive. When the pigeons had relearned the discriminations, the stimulus functions were reversed again. The pigeons were given more than 40 reversals successively. Performance on the first 40 different photographs in each session was below chance in the initial reversals, but improved during the course of successive-reversal training. Finally, after acquiring the reversal with only a few stimuli of each set, the pigeons were able to behave appropriately to the new contingencies in the presence of the remaining stimuli. The results suggest that successive-reversal training generated functional classes. Similar results from experiments using nonhuman animals have also been reported by other researchers (Delius, Ameling, Lea, & Staddon, 1995; Dube, McIlvane, Callahan, & Stoddard, 1993; von Fersen & Lea, 1990; Nakagawa, 1986, 1992).

The major aim of the present study was to establish functional classes in a chimpanzee using a successive-reversal training procedure as in Vaughan's (1988) experiment. In the present experiments, the subject was trained on a sequential responding task with two two-item lists. One female chimpanzee was presented a pair (or list) of stimuli (e.g., red and green) and was required to respond to each stimulus sequentially (e.g., red first, then green). Both stimuli terminated after the second response (simultaneous chaining; Straub & Terrace, 1981). This is the simplest form of a sequential-responding task. After the discrimination met the criterion, the order contingency was reversed for one of the two lists. If the subject responded to the remaining list according to the order reversal, it could be said that this behavior is analogous to those of the pigeons in Vaughan's experiment. I trained and tested sequential responding under between-session (Experiment 1) and within-session (Experiment 2) successive-reversal training procedures. Experiment 3 tested the nature of the controlling relations for sequential responding. In two-item sequential responding, there are several possible controlling relations. The subject's sequential responding may be controlled only by the first or second stimulus, or may be controlled by both. These possibilities were tested by presenting what might be called crossover lists, in which each stimulus came from different pairs (Lazar, 1977), and wild-card lists, in which a neutral stimulus (wild card) was substituted for one of the stimuli (D'Amato & Colombo, 1989). In an additional experiment (Experiment 4), trial-unique wild cards were introduced to enhance the control of sequential responding by both the first and the second stimuli in the list.

GENERAL METHOD

Subject

A 9-year-old female chimpanzee (*Pan troglodytes*), Chloe, served as the subject in the present experiments. She had an extensive training history in conditional discrimination tasks for approximately 4 years, including tests for symmetry and control by negative stimulus relations (Fujita & Matsuzawa, 1989; Tomonaga, 1993; Tomonaga & Matsuzawa, 1992; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991; Tomonaga, Matsuzawa, & Matano, 1991). She had no experience in language-like skill training or in sequential-responding tasks before the onset of the present experiments.

Chloe lived with three young chimpanzees in a cage with a sunroom. She maintained her free-feeding weight throughout the present study without special deprivation. Care and use of the chimpanzee adhered to the 1986 version of the *Guide for the Care and Use of Laboratory Primates* of the Primate Research Institute, Kyoto University.

Apparatus

The experimental booth for the chimpanzee (2.4 m by 2.0 m by 1.8 m) had a 14-in. CRT color monitor (28 cm by 21 cm) with an optical touch panel (Minato Electronics, Model TD-301). Touching the CRT screen was defined as a response. A BASIC software program divided the CRT screen into 12 areas (four columns and three rows). Computer-graphic stimuli could be presented in each area. A food tray was installed to the right of the monitor, and a universal feeder (Davis Scientific Instruments, Model UF-100) delivered a variety of foods (apples, pineapples, raisins, peanuts, etc.) into this tray. The equipment was controlled by a personal computer (NEC, Model PC-9801 F2).

Stimuli

In the present experiment, two pairs of stimuli were employed; a color pair, green to red, and a shape pair, star to snake (see Figure 1). Colors were displayed in rectangles (4 cm by 4 cm), and shapes were colored white on black backgrounds (3 cm by 3 cm). These stimuli had been used before in matching-to-sample training (Tomonaga, 1991, 1993; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991), in which red was bidirectionally related to white cross, green to white circle, star to light blue, and snake to yellow. However, no stimulus classes, either equivalence or functional, had been established among the stimuli employed in the present experiments.

Several novel stimuli were introduced in the latter part of the present study (Experiments 3 and 4). These are described in each section.

In the successive-reversal training, the *original* order was defined as touching green first, then red and as touching star first, then snake. The *reversed* order was defined as touching red first, then green and as touching snake first, then star. A *reversal* was defined as change of the contingency from the original to the reversed order or from the reversed to the original order.

When referring to the pairs irrespective of their order contingency, the form of X–Y is used, whereas when referring to them with respect to the order, the form of X-to-Y is used.

Sequential-Responding Procedure

Figure 1 shows a typical trial in the sequential-responding task. After a 3-s intertrial interval (ITI), three vertically striped bars (26 cm by 5 cm) were presented on the CRT for 1 s along with a 1-s beep. Then one of the bars disappeared and two stimuli were presented in two of four areas of a given row. The subject had to respond to the stimuli in a specific order. When the subject responded to a stimulus, a 0.1-s click was sounded as response feedback, but all the stimuli remained on at the same location (simultaneous chaining; Straub & Terrace, 1981). Repeated responding to the same stimulus had no programmed effect. If the subject responded to the stimuli in the correct order, all stimuli on the CRT, including the striped bars, terminated, a 1-s chime was presented as a "correct" signal, and food was delivered to the food tray, followed by a 3-s ITI. If her first response was to the second stimulus (as specified by the order contingency), all stimuli disappeared and a 0.5-s buzzer was presented as an error signal, followed by an additional 3-s timeout and the usual ITI. If the subject made an error, the trial was repeated until she made the correct responses. In the correction trials, the same stimuli as in the original trial appeared in different areas of a different row.

The left versus right positions of the stimuli were counterbalanced from trial to trial. Trials were randomized with the restriction that the same absolute positions of stimuli never appeared in succession, and that the same pair and relative left-right position never appeared on more than two consecutive trials. The row on which stimuli were presented was also randomized from trial to trial.

EXPERIMENT 1: BETWEEN-SESSION SUCCESSIVE-REVERSAL TRAINING

In Experiment 1, the chimpanzee was initially trained on two two-item lists. After the acquisition of sequential responding and the completion of a preliminary test, between-session successive-reversal training was introduced to establish functional classes. In the between-session successive-reversal training,

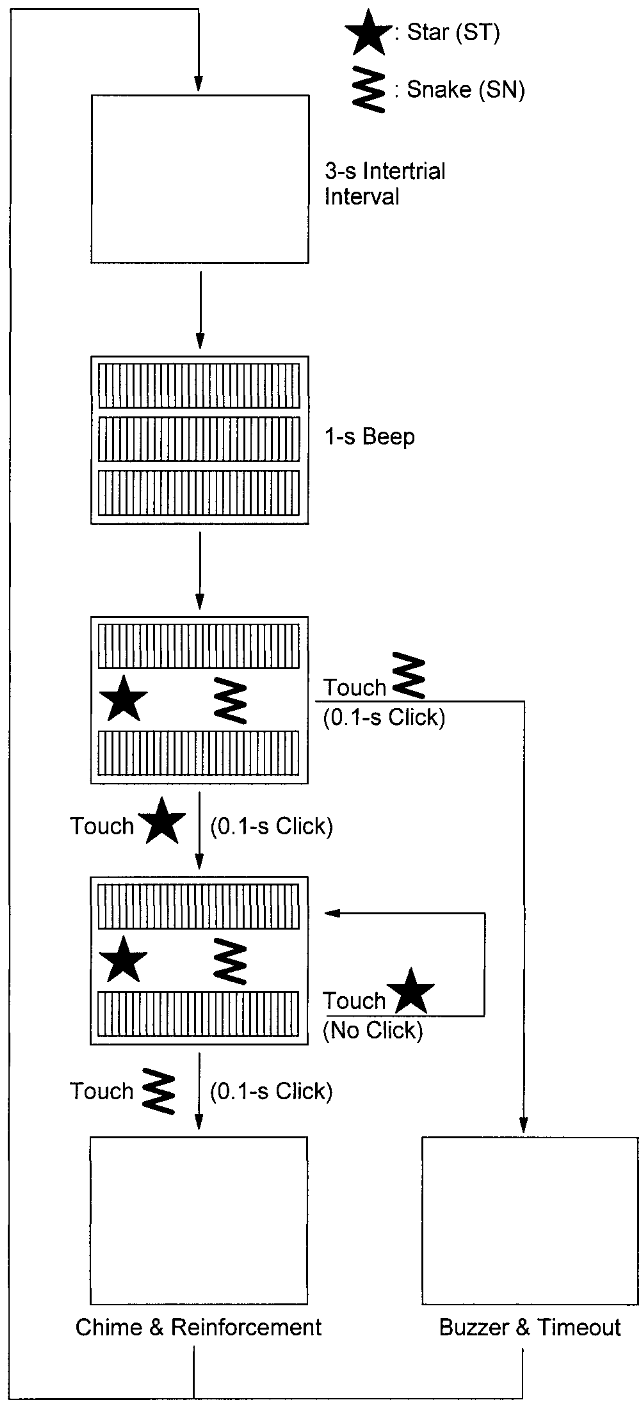

Fig. 1. Schematic representation of the procedure of the sequential-responding task.

the subject was first exposed to reversal training with one of the two lists. When the discrimination criterion was met, nonreinforcement probe trials with the other list pair were interspersed among the baseline trials during a test session. If functional classes were established during the training, the subject would select the probe stimuli in the same order as the current reinforced pair (i.e., original or reversed order). Sixteen reversal blocks were given.

Method

Sequential-Responding Training

Chloe was initially trained on the sequential-responding task. Each session consisted of 96 trials in which the two types of pairs (green to red and star to snake) appeared equally often. The correction procedure was in effect. Training continued until percentage correct exceeded 90% for two consecutive sessions.

Preliminary Test

After meeting the acquisition criterion, the subject was given a preliminary test for functional class formation, which was called the crossover test. Chloe was tested for four 104-trial sessions, in each of which eight nonreinforcement probe trials were interspersed randomly among the 96 baseline trials. Probe trials tested for green-to-snake and star-to-red response sequences. If functional classes had formed during training, the subject should respond appropriately to these crossover pairs (i.e., respond to green, then to snake, and respond to star, then to red) (Lazar, 1977). In probe trials, no feedback was produced by the subject's sequential responses, which immediately terminated all stimuli on the CRT and were followed by the ITI.

Before the onset of subsequent between-session successive-reversal training, Chloe was given one 96-trial session of baseline training with the original orders.

Between-Session Successive-Reversal Training

Each reversal block consisted of three phases. The first phase was the pretest reversal training. In each reversal block, Chloe was trained on one of the two pairs (hereafter referred to as the baseline pair) with the order contingency reversed from that of the previous block. Each session consisted of 96 trials, and no correction procedure was applied, because the same pair of stimuli (except for configuration) appeared on all trials. This training continued until percentage correct on the first 48 trials exceeded 85%. In the second phase, Chloe was given a single test session. The session consisted of 112 trials with the baseline pair and 12 nonreinforcement probe trials, in which the other pair (hereafter referred as to the tested pair) was presented. The first 16 trials consisted of only baseline trials, called warm-up trials. The 12 probe trials were interspersed randomly among the remaining baseline trials. In this probe test session, the correction procedure was applied to the baseline trials, unlike in the first phase, to prevent the subject from showing inappropriate behavior after error trials (e.g., long pausing). The third phase was the posttest training. Chloe was given differential-reinforcement training with the same order contingency (i.e., reversed or original, depending on the block) for both lists. Each session consisted of 96 trials, in which each pair appeared 48 times in random order. Percentage correct was calculated for each pair within the first 48 trials, during which each pair appeared 24 times. The correction procedure was also in effect. The criterion for this training was that the subject make more than 90% correct responses to each pair within the first 48 trials for two consecutive sessions.

Table 1

Four types of reversal blocks in Experiment 1.

Baseline pair	Tested pair	Order contingency
G → R	ST → SN	Original
R → G	SN → ST	Reversed
ST → SN	G → R	Original
SN → ST	R → G	Reversed

Note. G = green; R = red; ST = star; SN = snake.

The original- and reversed-order contingencies were alternated across reversal blocks. Table 1 shows the four types of reversal blocks. Each type of reversal block was repeated four times in a random order.

Results

Acquisition and Preliminary Test

Chloe met the sequential-responding criterion after 28 sessions of training. In the pre-

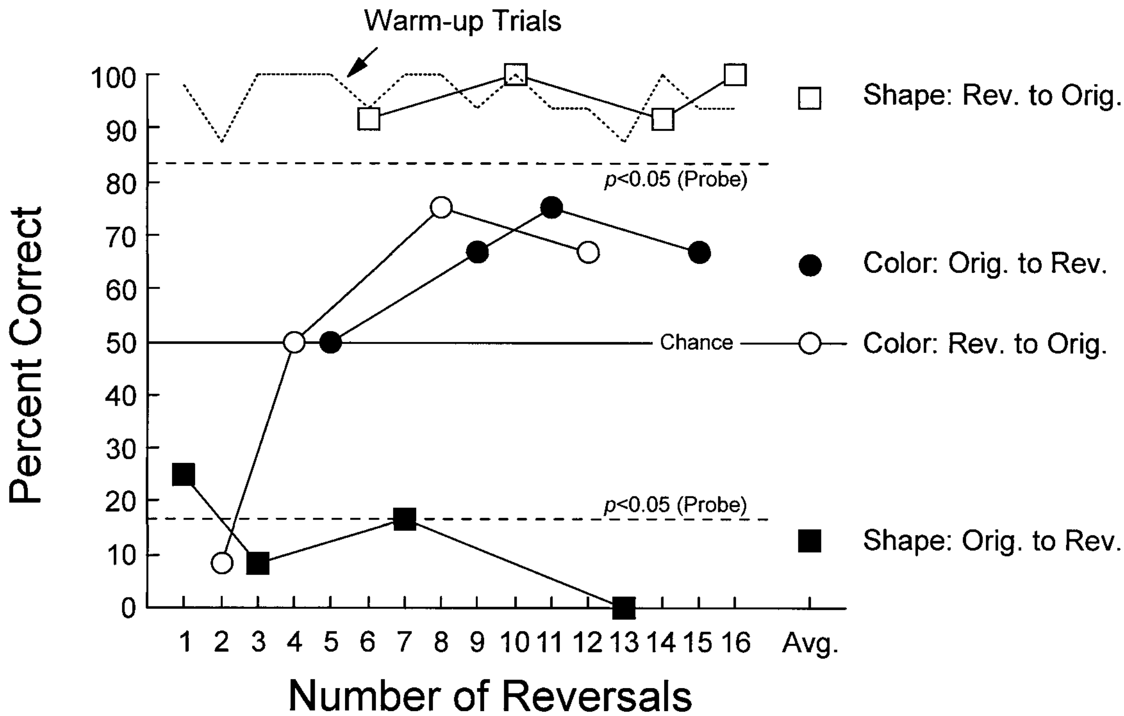

Fig. 2. Percentage correct on warm-up and probe trials in Experiment 1. The dotted line indicates the percentage correct on the warm-up trials. Circles indicate the results of the color pair, and squares indicate those of the shape pair. Open points indicate the results under the original-order contingency, and filled points indicate those under the reversed-order contingency. Data points are connected for each type of probe trial. Horizontal lines at 83.3% (10/12) and 16.7% (2/12) indicate upper and lower limits of significance for probe trials (using 5% with binomial test).

liminary crossover test, Chloe was 100% correct on the star-to-red trials, but she showed chance-level performance (50% correct) on the green-to-snake trials.

In the between-session successive-reversal training, Chloe changed the response order almost in a single pretest reversal-training session. Mean percentage correct for the first 48 trials in the criterional sessions in this phase was 93.8% (averaged across all blocks). Percentage correct for the last 48 trials in the first pretest reversal-training session of each block was always 100%. In posttest training, percentage correct for the first 48 trials in the first session always exceeded 80%, ranging from 80.2% to 100%.

Between-Session Successive-Reversal Training

Figure 2 shows percentage correct for the first 16 warm-up trials and for the 12 probe trials in the test sessions. Data points are connected for each type of reversal block. Chloe performed very well in the warm-up trials (96.0% average across all blocks). The results of the probe trials, however, were rather inconsistent. Only in the reversed-to-original blocks with the shape test pair did she show consistently above-chance probe-trial performance. Her performance improved during the course of the reversals only in the reversed-to-original blocks with the color test pair. Probe-trial performance in the original-to-reversed blocks with the color test pair was above chance but not significantly so. Furthermore, the reversed contingency did not transfer from the color baseline pair to the shape test pair in the original-to-reversed blocks, in which Chloe consistently responded from star to snake in the probe trials, although she reversed the order of the color pair on baseline trials. To summarize, when the contingency was changed from the reversed to the original order, Chloe responded on probe trials in the order trained in pretest reversal sessions. When the contingency was changed from original to reversed order, however, her performance on probes (for shape) was consistent with the order trained in the previous reversal block (i.e., the order trained originally).

Discussion

In the preliminary crossover test, no strong evidence for the formation of functional classes was obtained. Moreover, the results of the between-session successive-reversal training also provided no clear evidence of the development of functional classes. Instead, the results suggest an asymmetry of effects of the reversal training (i.e., better for the reversed-to-original than for the original-to-reversed contingency). The reason for this asymmetry is unclear. In the test sessions, baseline and probe trials could be discriminated easily based on stimulus features. Performance on probe trials might have been controlled by the original contingency to which the subject was exposed longer than to the reversed contingency.

EXPERIMENT 2: WITHIN-SESSION SUCCESSIVE-REVERSAL TRAINING

In Experiment 2, further attempts were made to establish functional classes using a within-session successive-reversal training procedure. In addition to this procedural change, the subject's performance on probe trials was differentially reinforced.

Method

Within-Session Successive-Reversal Training

Figure 3 shows examples of two successive sessions in Experiment 2. Each session consisted of 96 trials, divided into three 32-trial blocks. The reinforced order alternated from block to block. For example, in session $n - 1$, the original response order was reinforced in the first block, whereas the reversed order was reinforced in the second block. In the third block, the original order contingency was in effect again. The next *n*th session began with a block in which the reversed response order was reinforced.

The same pair of stimuli (baseline pair) appeared in the first two trials of each block, called the pretest reversal trials. In the third trial, called a probe test trial, the remaining pair (tested pair) was presented. Unlike in Experiment 1, the sequential responses on probe test trials were differentially reinforced. If the subject responded appropriately to the new contingencies on the probe test trial, a 1-s chime and food were given to her, whereas an error buzzer and timeout followed the first response to the second stimulus (i.e., incorrect response). In the fourth and following trials, called posttest trials (Trials 4 through 32), each of the two types of pairs appeared with a probability of .5. The correction procedure was in effect for all trial types in this experiment. If functional classes were established through this within-session successive-reversal training, Chloe should come to respond to the tested pair in the same order (i.e., original or reversed) trained for the reinforced pair in the first two trials of each block.

This within-session successive-reversal training was continued for 64 sessions. The first block in each session was identified as a between-session reversal. The results of the first block were included in the data analysis. The subject experienced 192 reversals in total: 128 within-session reversals and 64 between-session reversals.

Results and Discussion

Figure 4 shows percentage correct for the first, second (pretest reversal), third (probe test), and fourth (posttest) trials of each trial block combined across eight sessions. Thus, each point is based on 24 trials (3 blocks in a session $\times$ 8 sessions).

The most important outcome from the present experiment is the improvement over sessions in accuracy on the third trial, on which the tested pair was first presented. Performance on these probe test trials was below chance during the first two session blocks, then gradually improved from the second to fifth session blocks, and finally reached a level significantly above chance. Mean percentage correct on the third trial over the last two session blocks was 95.8%; that is, Chloe changed the order of responses on the tested pair after a baseline pair was reinforced in the pretest reversal trials only twice.

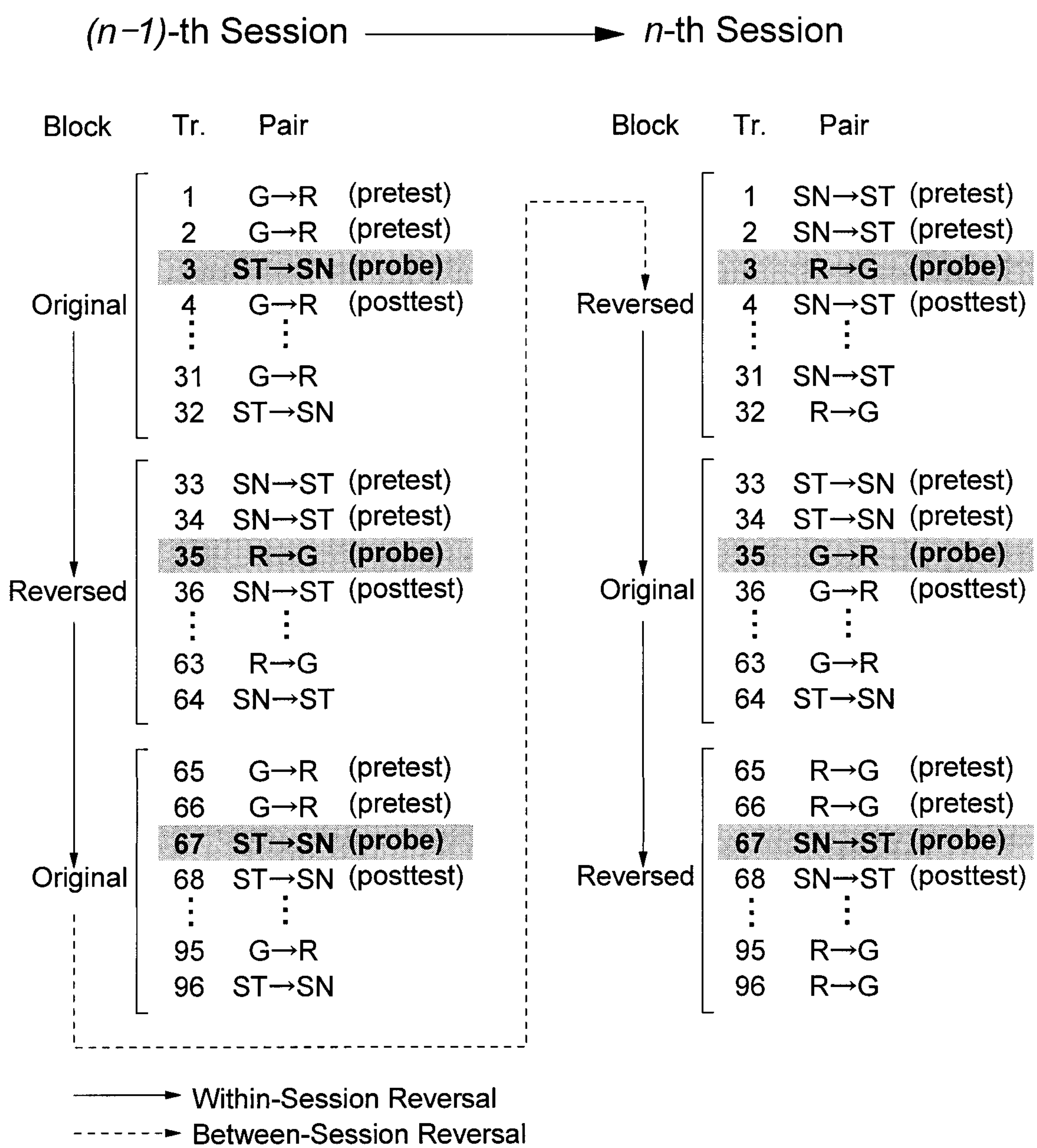

Fig. 3. Examples of two sessions in Experiment 2. See text for details.

Because Chloe always responded in the original order on the first trial of the first trial block in each session, percentage correct on the first trial for all the trial blocks in each session was maintained above 0%, although it was significantly below chance. In an eight-session block, the original order appeared four times in the first trial block; the expected value for percentage correct on the first trials was therefore 16.7% (4/24). Her accuracy on the first trial was almost the same as this expected value. Mean percentage correct on the first trials from all sessions excluding those in the first trial block was 1.6%; she responded "correctly" only twice in the first trials of the second and third trial blocks.

Performance on second trials was very high and showed improvement across session

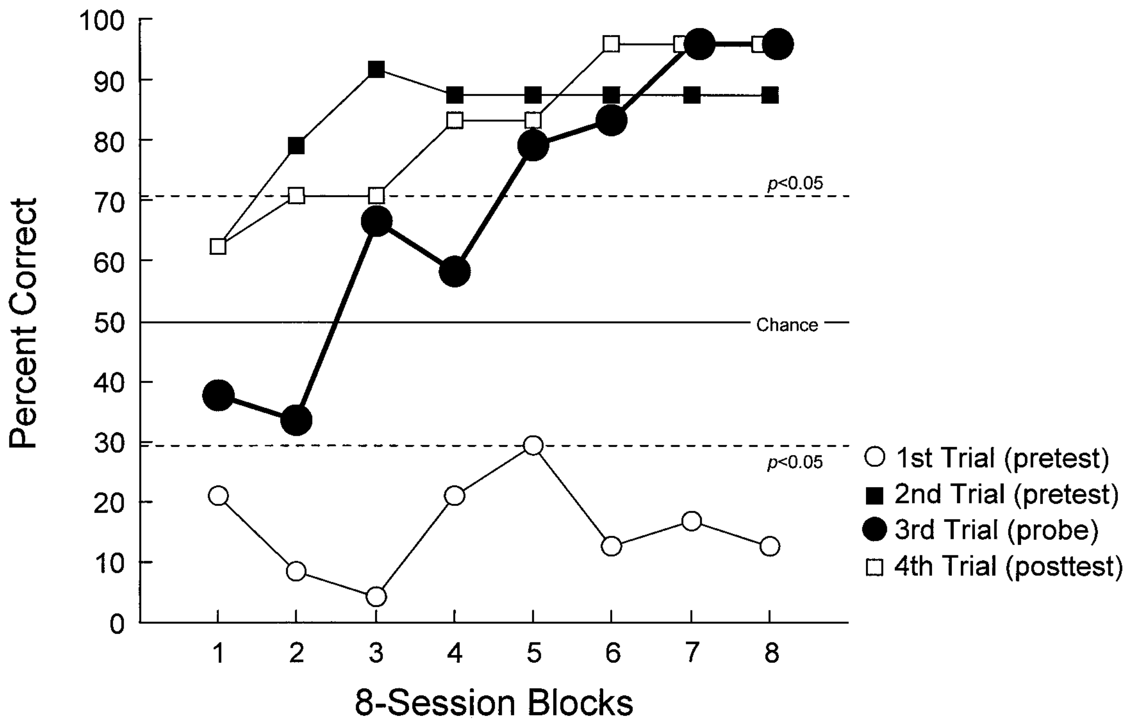

Fig. 4. Percentage correct for the first, second, third, and fourth trials in each 32-trial block averaged across eight sessions in Experiment 2. Each point is based on 24 trials. Horizontal lines at 70.8% (17/24) and 29.2% (7/24) indicate upper and lower limits of significance (using 5% with binomial test).

blocks. These results indicate that the successive-reversal training had a facilitative effect on the subject's reversal responding; Chloe learned to change the response order when she experienced the reversal of order after a few trials. These results were the same as those in previous studies on successive-reversal training of a simple simultaneous discrimination with a single stimulus set by chimpanzees (Schusterman, 1962). Percentage correct on the fourth (posttest) trial was almost the same as that of the second trial, and increased to above 80% over the first four session blocks.

The results on the third trials are in part parallel to those obtained in Vaughan's (1988) experiment with pigeons on successive-reversal training of successive discrimination between arbitrarily partitioned sets of tree photographs. The present results suggest that functional classes can be established through within-session successive-reversal training with the chimpanzee.

In Experiment 2, there were two major procedural changes from the previous experiment. First, contingency reversals occurred within sessions. Second, the subject's responding on the third trials (probe trials) was differentially reinforced. This was not the case in the previous experiment in which nonreinforcement probe trials were used to assess transfer of reversal responding from one list to another. Differential reinforcement during the successive-reversal training has been shown to facilitate the establishment of functional classes in humans and pigeons (Sidman et al., 1989; Vaughan, 1988). The present results suggest that the differential reinforcement of reversals may have facilitated the establishment of functional classes in the chimpanzee as well.

In the present experiment, the effects of within-session reversal training could not be distinguished from the effects of differential reinforcement on probe trials. If differential reinforcement had been employed in the between-session reversal training, results similar to those of the present experiment might have been obtained. This possibility should be examined in the future.

Table 2

Summary of the three tests conducted in Experiment 3.

	Number of sessions	Tested pairs in original-order blocks (number of repetitions)[a]	Tested pairs in reversed-order blocks (number of repetitions)
Crossover test	8	G → SN (2), ST → R (2)	SN → G (2), R → ST (2)
Nonreinforced wild-card test	8	G → WC (1), WC → R (1), ST → WC (1), WC → SN (1)	R → WC (1), WC → G (1), SN → WC (1), WC → ST (1)
Differentially reinforced wild-card test	8	G → WC (2), WC → R (2), ST → WC (2), WC → SN (2)	R → WC (2), WC → G (2), SN → WC (2), WC → ST (2)

[a] Number of repetitions in a trial block.

EXPERIMENT 3: CROSSOVER AND WILD-CARD TESTS DURING WITHIN-SESSION SUCCESSIVE TRAINING

The results of the previous experiments did not provide detailed information about the nature of the controlling relations in the present two-item sequential-responding task. In Experiment 3, three tests were given to Chloe in order to clarify the characteristics of the functional classes established through successive-reversal training.

Method

Stimuli

In addition to the training stimuli, a novel stimulus was used as the wild card in the wild-card tests. This stimulus was a rectangle (2.5 cm by 2.5 cm) composed of randomly positioned colored dots. Seven colors of dots were equally and randomly distributed within the rectangle.

Crossover Test

The first test was a crossover test in which members of each list were combined; specifically, green–snake and star–red pairs were tested (Lazar, 1977; Sidman et al., 1989). This test had first been presented before the onset of between-session reversal training in Experiment 1, and it showed no evidence of the formation of functional classes. The upper row of Table 2 shows a summary of the crossover test procedures. In this test, each session consisted of 96 baseline (two training pairs) and 12 probe trials. A session was divided into three 36-trial blocks. Each trial block consisted of 32 baseline and four probe trials. As in Experiment 2, the order contingency was changed from block to block. The successive-reversal training was identical to that in Experiment 2.

Probe trials never appeared in the first eight trials of each trial block; the four probe trials were randomly interspersed among the 24 subsequent baseline trials of the trial block. In the probe trials, each of the two crossover lists, green–snake and star–red, appeared twice. Responses on the probe trials were neither reinforced nor given the chime, buzzer, or timeout. When the subject responded to the two stimuli successively, all stimuli on the CRT disappeared and the ITI began immediately. Responses to green first, then snake, and to star first, then red in the original-order blocks, and to snake first, then green and to red first, then star in the reversed-order blocks were considered to be ‘‘correct’’ responses. The correction procedure was in effect (except for nonreinforcement probe trials) for this and the subsequent tests. The crossover test consisted of eight sessions. The first test session started with a reversed-order trial block.

Nonreinforcement Wild-Card Test

After the crossover test, the subject was shifted to the nonreinforcement wild-card test (see middle rows of Table 2). In each test trial, one of the members of a list was replaced with a common novel stimulus (the wild card; WC) (cf. D'Amato & Colombo, 1989). If functional classes had been established for each list member, the subject should respond to the tested pairs in the order defined by the functional classes. This procedure was in part the same as an S+/S− control test or substitution test in a simple discrimination (Rapp, 1990).

A session consisted of 96 baseline (two training pairs) and 12 probe trials, as in the crossover test. Each session was divided into the three 36-trial blocks. Order contingency alternated from block to block. Four types of tested pairs were prepared by pairing each trained stimulus and the wild card; green–WC, red–WC, star–WC, and snake–WC. Each tested pair appeared once in a trial block. Relative left-right positions of stimuli on probe trials were counterbalanced within a session. As in the crossover test, responses on probe trials were not followed by any feedback. In the original-order blocks, correct response orders for tested pairs were green to WC, WC to red, star to WC, and WC to snake. In the reversed-order blocks, they were WC to green, red to WC, WC to star, snake to WC. The subject was given eight sessions of this test.

Differential-Reinforcement Wild-Card Test

The bottom rows of Table 2 summarize the differential-reinforcement wild-card test. In this test, responses on wild-card probe trials were differentially reinforced to explore the disruptive effect of nonreinforced probe trials on Chloe's probe and subsequent baseline performance. A session consisted of 96 baseline (two training pairs) and 24 probe trials. As in the previous tests, each session was divided into the three 40-trial blocks (32 baseline and eight probe trials), in which order contingency alternated. Four types of tested pairs appeared twice in each trial block. If the subject responded first to the stimulus designated as second by the order contingency in a probe trial, all stimuli disappeared, the error buzzer was sounded, and timeout was added to the usual ITI. In the correction trial following probe-trial errors, the baseline pair in which the trained stimulus was substituted for the wild card was presented. For example, if the subject made an error on the probe trial in which the green–WC pair was presented, the green–red pair appeared in the correction trial. This test consisted of eight sessions.

RESULTS

Baseline Successive-Reversal Training

The results of successive-reversal training during the three test series were similar to those in Experiment 2. Mean percentage correct on all test sessions (i.e., 24 sessions, 72 trial blocks) was 16.7% for the first trial in each trial block, 95.8% for the second trial, 90.3% for the third trial, and 90.3% for the fourth trial.

Probe Trials

Crossover test. Figure 5A shows the results from the crossover probe trials. Because each bar is based on 24 trials, the significance levels at 5% of the binomial test are above 70.8% and below 29.2%. In the original-order trial blocks, Chloe responded in the correct order for both tested pairs at levels significantly above chance. On the other hand, in the reversed-order trial blocks, her performances were inconsistent. She showed significantly above-chance performance on the red-to-star pair, but she responded randomly on the snake-to-green pair. The chi-square test revealed a significantly better accuracy in probe trials of original-order trial blocks than those of the reversed-order trial blocks, $\chi^2(1) = 13.19$, $p < .001$.

Nonreinforcement wild-card test. Figure 5B shows the results from nonreinforcement wild-card probe test trials. Each bar is based on 12 trials; therefore the significance levels of binomial tests are above 83.3% and below 16.7%. Chloe showed relatively better accuracy on probe trials in the original-order trial blocks than in the reversed-order trial blocks, $\chi^2(1) = 3.64$, $.05 < p < .1$. In both the original- and the reversed-order trial blocks, performances on probe trials in which the subject had to respond to the wild card second (WC-second trials) were better than chance. Performances on probe trials in which Chloe had to respond to the wild card first (WC-first trials) were almost at chance level except on the WC-to-green pair in the reversed-order blocks, in which accuracy was significantly lower than chance. Chi-square tests revealed that the number of correct trials in the WC-second probe trials was significantly better than in the WC-first trials: original-order trial blocks, $\chi^2(1) = 6.75$, $p < .05$; reversed-order trial blocks, $\chi^2(1) = 14.18$, $p < .001$.

Differential-reinforcement wild-card test. Figure 5C shows the results on probe trials during the differential-reinforcement wild-card test. Each bar is based on 24 trials, and significance levels of binomial tests are above 70.8%

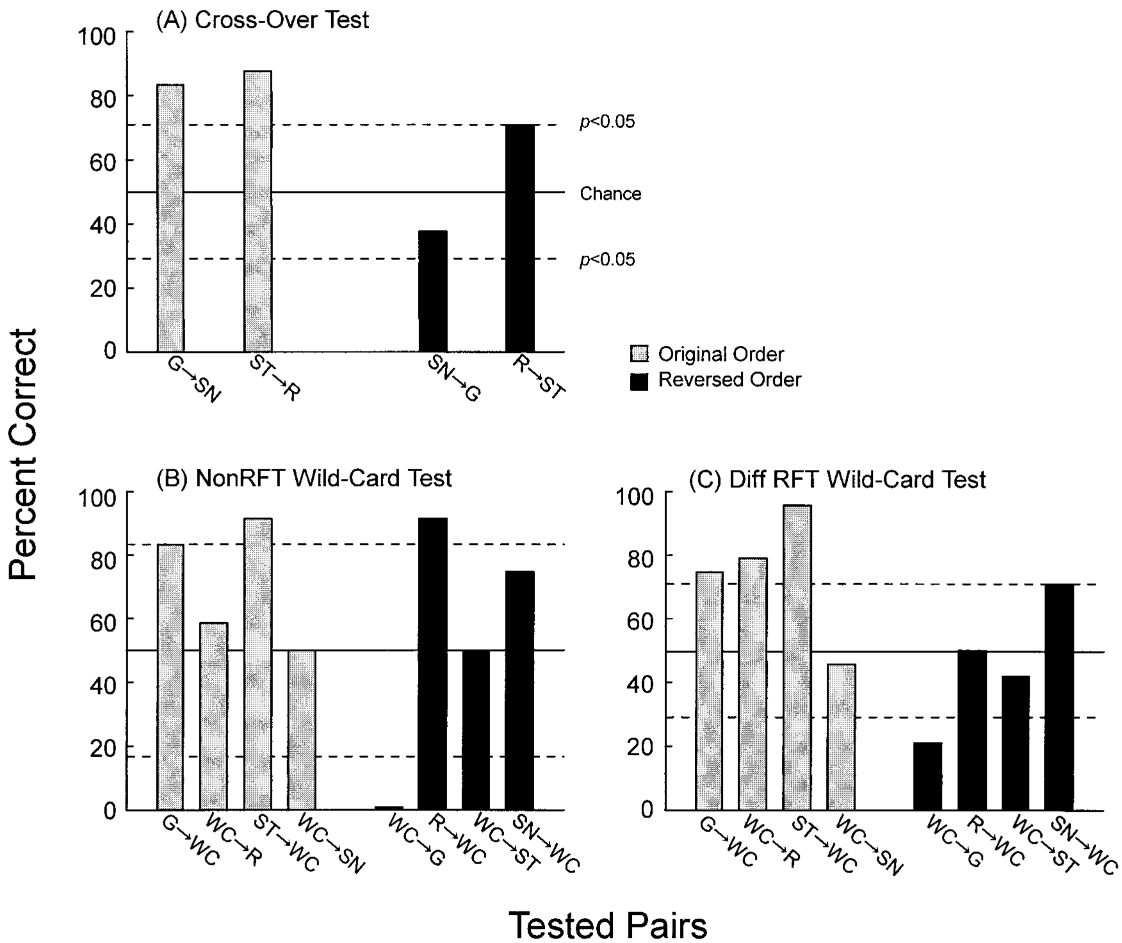

Fig. 5. Results of probe trials in (A) the crossover, (B) the nonreinforcement wild-card, and (C) the differential-reinforcement wild-card tests in Experiment 3. Gray bars indicate the results in the original-order blocks, and black bars indicate those in the reversed-order block. Dotted lines indicate upper and lower limits of significance (using 5% with binomial test).

and below 20.9%. Chloe showed significantly better performance on probe trials in the original-order trial blocks than in the reversed-order trial blocks, $\chi^2(1) = 15.81$, $p < .001$, as in the previous wild-card test. In the original-order trial blocks, performances on tested pairs were significantly above chance except on the WC-to-snake pair, in which the subject showed chance performance. A chi-square test revealed a significant difference in the number of correct probe trials between the WC-first and the WC-second probe trials, as in the nonreinforcement wild-card test, $\chi^2(1) = 6.54$, $p < .05$. In contrast, performances were above chance only in the snake-to-WC pair, and were below chance in the WC-to-green pair in the reversed-order blocks. The difference in accuracy between the WC-first and the WC-second trials was also significant, $\chi^2(1) = 17.08$, $p < .001$.

Baseline Error Pattern Analyses

Tables 3, 4, and 5 depict the percentage of errors for all baseline trials immediately before and after the crossover (Table 3), nonreinforcement wild-card (Table 4), and differential-reinforcement wild-card (Table 5) probe trials. Chi-square tests were conducted to test for differences in the number of errors on trials before and after probe trials. These tables also show the results of these analyses. Chloe seldom made errors immediately be-

Table 3

Percentage of errors (and number of errors/trials) on baseline trials before and after probe trials for crossover tests in Experiment 3.

Types of blocks	Before probe	After probe	χ^2
Original order	0 (0/48)	41.7 (20/48)	22.80***
Reversed order	0 (0/48)	8.3 (4/48)	2.35

Note. Asterisks indicate the significant difference in the number of errors between before and after probe trials ($df = 1$). *** $p < .001$.

Table 4

Percentage of errors (and number of errors/trials) on baseline trials before and after probe trials for nonreinforcement wild-card tests in Experiment 3.

Types of blocks	Before probe	After probe	χ^2
Original order	2.1 (1/48)	18.8 (9/48)	5.47*
Reversed order	2.1 (1/48)	35.4 (17/48)	15.38***

Note. Asterisks indicate the significant difference in the number of errors between before and after probe trials ($df = 1$). * $p < .05$, *** $p < .001$.

fore probe trials, whereas she often made errors immediately after the probe trials, except in the reversed-order trial blocks during the crossover test. During the differential-reinforcement wild-card test (Table 5), when Chloe responded correctly on a probe trial, she made few errors on the next baseline trial. When she made an error on a probe trial, however, she made more errors after the probe trial than before. Differences in the number of errors on baseline trials following correct versus error probes were also significant: original, $\chi^2(1) = 53.68$, $p < .001$; reversed, $\chi^2(1) = 4.75$, $p < .05$.

Discussion

In the crossover test, Chloe's percentage of correct responses on test trials was higher in the original-order trial block than in the preliminary crossover test conducted in Experiment 1. This result may suggest the formation of functional classes during successive-reversal training. The fact that Chloe showed chance performance in the reversed-order blocks, however, weakens this conclusion. This asymmetry of stimulus control between the original and the reversed order was also observed in nonreinforcement probe trials in Experiment 1. Performance on nonreinforcement probe trials may be insensitive to changes in the baseline contingency (cf. Pilgrim & Galizio, 1990).

Two series of wild-card tests showed the same asymmetry in probe performance between original- and reversed-order trial blocks observed in the crossover test. Furthermore, Chloe apparently avoided touching the WC first in both the original- and reversed-order trial blocks, but especially in the reversed-order blocks in which she responded correctly on only 25% of the WC-first trials ($p < .05$, binomial tests) and on only 31.3% of these trials in the differential-reinforcement test ($p < .01$). These results might suggest that Chloe responded to a trained stimulus first, avoiding a novel stimulus (i.e., wild card) by responding to it later (cf. Farthing & Opuda, 1974). However, if this novel-stimulus avoidance had consistently dominated the control of sequential responding, there would have been no difference in WC avoidance on the WC-first trials for original- versus reversed-order trial blocks. In fact, Chloe showed chance-level performance rather than WC avoidance on WC-first probes in the original-order trial blocks (54.2% correct in the nonreinforcement test and 62.5% correct in the differential-reinforcement test). Chi-

Table 5

Percentage of errors (and number of errors/trials) on baseline trials before and after probe trials for differential-reinforcement wild-card tests in Experiment 3.

Types of blocks	Before correct probe	After correct probe	χ^2	Before incorrect probe	After incorrect probe	χ^2
Original order	1.4 (1/71)	1.4 (1/71)	0.51	0 (0/25)	72.0 (18/25)	25.09***
Reversed order	6.8 (3/44)	13.6 (6/44)	0.50	1.9 (1/52)	32.7 (17/52)	15.12***

Note. Asterisks indicate the significant difference in the number of errors between before and after probe trials ($df = 1$). *** $p < .001$.

square tests revealed that there was a significant difference in accuracy on WC-first probes for original- versus reversed-order trial blocks: nonreinforcement test, $\chi^2(1) = 4.27$, $p < .05$; differential-reinforcement test, $\chi^2(1) = 9.41$, $p < .01$. This difference cannot be explained by novel-stimulus avoidance alone. Asymmetry in strength of original- versus reversed-order contingency might have also affected performance on tests.

The present results on wild-card tests might suggest that sequential responding was controlled by the first stimulus, not by the second or both stimuli. The subject's sequential responding was well maintained irrespective of the changes of the second stimulus. If the second stimulus has acquired control over the sequential responding as ''avoid responding to the second stimulus first,'' the subject might have shown high accuracy on WC-first trials. The present results of poor performance on WC-first trials might be analogous to a lack of S$-$ control in the simple simultaneous discrimination (cf. Carter & Werner, 1978; Rapp, 1990). In the two-item sequential-responding context, the second response may have little role in the chains of ''sequential'' responses. The second response may be only for terminating the trial and getting the reward. In the present experiment, therefore, Chloe might have responded to stimuli sequentially not as ''first, then *second,*'' but as ''first, then *finish.*'' If lists longer than two items had been used, such issues could be addressed more fully.

In the first two test series in which nonreinforcement probe trials were presented, Chloe made more errors on baseline pairs (i.e., changed the response order) after probe trials than before them (Tables 3 and 4). These results suggest that the subject may have changed the response order during successive-reversal training whenever food was not presented in the previous trial (i.e., based on one kind of lose-shift strategy). This account is further supported by the fact that Chloe made more errors on baseline trials after she made an error on differential-reinforcement probe trials than after she made correct responses on them in the differential-reinforcement wild-card test (Table 5). Thus, it was not the insertions of the probe trials per se, but the outcome that caused the change in response order. Chloe had extensive training on various discrimination tasks with correction procedures including the present experiments (Fujita & Matsuzawa, 1989; Tomonaga, 1993; Tomonaga & Matsuzawa, 1992; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991; Tomonaga, Matsuzawa, & Matano, 1991). It is likely that the performance on baseline trials after the probe trials observed in this experiment had been established through the correction procedure.

EXPERIMENT 4: SEQUENTIAL RESPONDING WITH TRIAL-UNIQUE WILD CARDS

The results of Experiment 3 suggest a lack of control over the second response by the stimulus that was to be selected second. Control by the second stimuli seems analogous to control by negative stimuli in simple and conditional discriminations (Carter & Werner, 1978; Cumming & Berryman, 1965; McIlvane et al., 1987; Rapp, 1990; Tomonaga, 1993). In Experiment 4, 96 Chinese characters were used as trial-unique wild-card stimuli to encourage the control of sequential responding by both the first and second stimuli. On some trials, a trial-unique wild card was substituted for one of the items of the two-item list. The use of trial-unique stimuli might prevent the development of inappropriate control by stimulus configurations (Carter & Werner, 1978; Wright, Cook, Rivera, Sands, & Delius, 1988). In addition to the color and shape lists, a novel list consisting of random-shape (RS) to inverted U-shape (U) was trained exclusively with the wild-card procedure. That is, during training, the RS-to-WC and WC-to-U pairs were presented but RS-to-U was not. After the initial training, transfer of sequential responding to new wild cards (additional sets of Chinese characters and Japanese characters, *kana*) was investigated using differential reinforcement. Transfer of sequential responding from the RS-to-WC and WC-to-U lists to the RS-to-U list was also tested with nonreinforcement probe trials. When these training and testing phases were completed, all contingencies were reversed and transfer of the reversed contingency to the RS–U pair was tested.

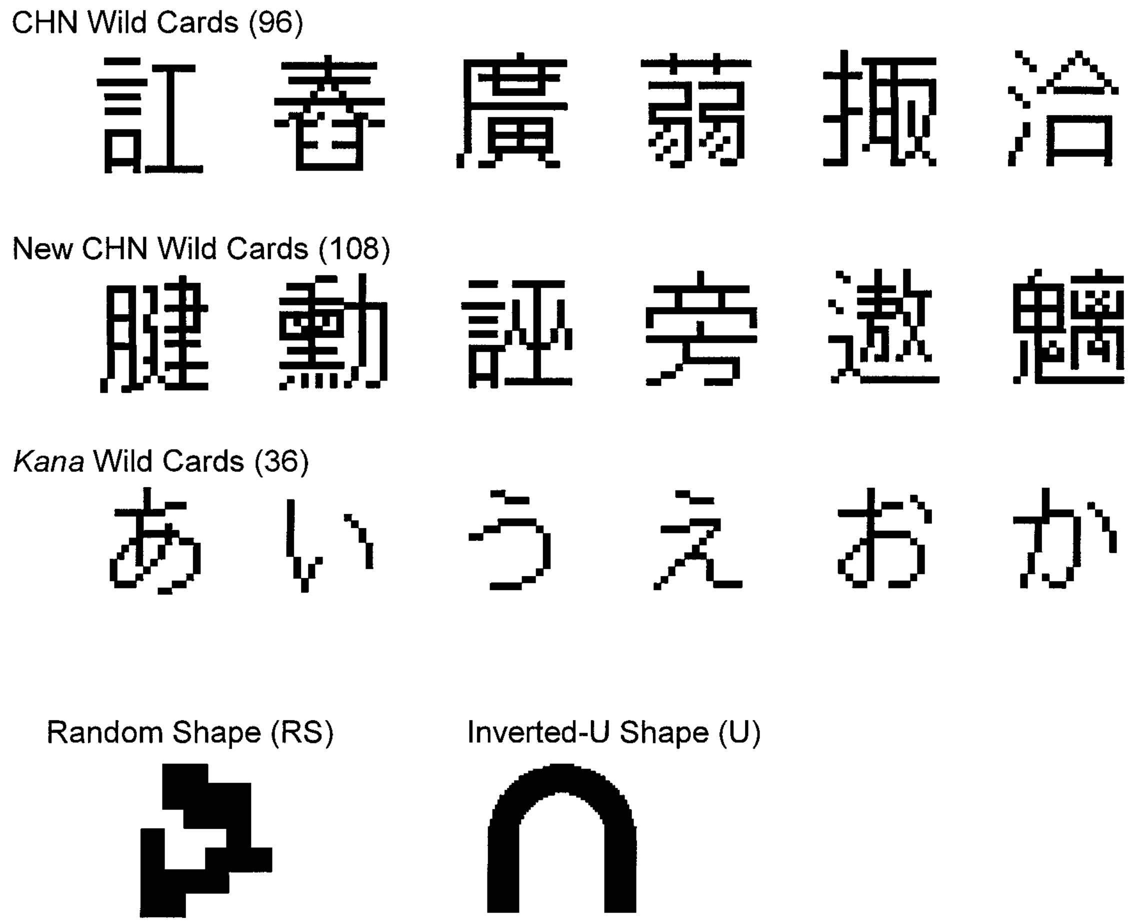

Fig. 6. Examples of the three types of new wild-card sets and two novel stimuli used in Experiment 4.

Method

Stimuli

Figure 6 shows examples of the three types of wild cards employed in the present experiment: 96 Chinese-character (CHN) wild cards, 108 additional CHN wild cards, and 36 kana wild cards. All stimuli were 2.5 cm by 2.5 cm and were composed of rectangular pixels (2 mm by 2 mm). CHN wild cards were of similar complexity, whereas kana wild cards were relatively simpler and consisted of more curved lines than CHN wild cards. The preliminary training of identity matching with these stimuli before the onset of this experiment showed that they were distinguishable from one another for the chimpanzee.

In addition to the green–red and star–snake lists, a novel list, RS–U, was introduced. These stimuli are shown in the bottom of Figure 6. They were 3 cm by 3 cm. The original order was defined as touching the RS first, then the U, and the reversed order was defined as touching the U first, then the RS. Sequential responding with these stimuli was trained only with wild cards (i.e., RS with WC or U with WC). The RS–U (no WC) pair was presented only in nonreinforcement probe test trials.

Training Sequential Responding with Trial-Unique Wild Cards

Figure 7 summarizes each phase of Experiment 4. During all phases, the correction procedure was applied. Wild cards were different from each other on every trial on which they appeared during a session, except

<table>
<tr><th rowspan="2">Training / Testing Phase</th><th rowspan="2">Number of Sessions</th><th colspan="3">Types of Pairs</th><th rowspan="2">Types of WCs</th><th rowspan="2">Reinforcement Schedule</th></tr>
<tr><th>Color Pairs</th><th>Shape Pairs</th><th>RS–U Pairs</th></tr>
<tr><td>Training with Trial-Unique WCs and Introduction of WC→U</td><td>14</td><td rowspan="6">G→R
G→WC
WC→R</td><td rowspan="6">ST→SN
ST→WC
WC→SN</td><td>WC→U</td><td rowspan="3">96 CHN Set</td><td rowspan="2">CRF</td></tr>
<tr><td>Introdusction of RS→WC</td><td>8</td><td rowspan="2">WC→U
RS→WC</td></tr>
<tr><td>Intermittent Reinforcement</td><td>17</td><td rowspan="2">VR 1.5 (Feedback)</td></tr>
<tr><td>Transfer to New WCs (1)</td><td>6</td><td rowspan="3">WC→U
RS→WC
RS → U
(Probe only)</td><td rowspan="2">96 CHN Set
New CHN Set
Kana Set</td></tr>
<tr><td>Transfer to New WCs (2)</td><td>6</td><td>VR 1.5 (Non Feedback)</td></tr>
<tr><td>Training with Old WCs</td><td>2</td><td rowspan="2">96 CHN Set</td><td rowspan="2">VR 1.5 (Feedback)</td></tr>
<tr><td>Reversal Training</td><td>12</td><td>R→G
WC→G
R→WC</td><td>SN→ST
WC→ST
SN→WC</td><td>U→WC
WC→RS
U → RS
(Probe only)</td></tr>
</table>

Fig. 7. Summary of training and testing phases in Experiment 4.

for correction trials, in which the same wild card was presented as in the previous error trial. The training consisted of two phases, introduction of the WC-to-U pair and introduction of the RS-to-WC pair. In the first phase, a session consisted of 84 trials. Seven kinds of pairs appeared 12 times each (see Figure 7). This phase was continued for 14 sessions. In the second phase, 12 RS-to-WC trials were added to the 84 trials, so that eight kinds of pairs appeared equally often. Chloe was given eight sessions.

Training with Intermittent Reinforcement

After training with wild cards and the introduction of the RS–U pairs with wild cards, a trial-based variable-ratio (VR) 1.5 schedule was introduced (cf. Tomonaga, 1993) with the same trial composition. Food reinforcers were delivered for correct responses on every two trials out of three. On nonreinforcement trials, a correct response produced a 0.5-s chime, whereas on reinforcement trials a correct response produced food reinforcers and the 1-s chime. If the subject made an error on a programmed nonreinforcement trial, the error buzzer was presented and the correction procedure was in effect. Nonreinforcement trials never appeared in succession. This intermittent-reinforcement training was continued for 17 sessions.

Transfer Training with New Wild Cards and Test with the RS–U Pair

After completion of the intermittent-reinforcement training, two types of additional wild cards were introduced. One was a set of 108 new CHN wild cards and the other was a set of 36 kana wild cards. Each session consisted of 97 trials, in which 24 of these trials were without wild cards, 72 were with wild cards, and one trial was a RS–U probe trial. Among the 72 WC trials, old CHN wild cards appeared 48 times, new CHN wild cards appeared 18 times, and kana wild cards appeared six times. Correct responses on all these trials were differentially reinforced on the VR 1.5 schedule. In the first six sessions, the 0.5-s chime was given, and in the last six sessions no feedback was given on nonreinforcement trials. This nonfeedback phase was included to test for disruptive effects of nonfeedback on the subject's performance (see Experiment 3). If the subject made an error on a nonreinforcement baseline trial, the error buzzer was presented and the correction procedure was in effect, as in the previous phase. From the third session of this phase, a nonreinforcement probe trial in which the RS and U appeared was added as the last trial of each session. The transfer training was continued for 12 sessions. After the 12-session transfer training, Chloe was given two additional sessions of training with only the old CHN stimuli used on wild-card trials. The VR 1.5 schedule with feedback was also in effect during this phase. The RS–U probe trial also appeared in these sessions, so that Chloe was given 12 RS-to-U probe trials in total.

Reversal Training

After the two sessions of training with old wild cards, all contingencies were reversed. A session consisted of 97 trials as in transfer training. Wild-card stimuli were all from the old CHN set. The last trial of each session was a U-to-RS nonreinforcement probe trial. The VR 1.5 with feedback was applied to all other trial types in reversal training, which was continued for 12 sessions. Chloe was given 12 U-to-RS probe trials in this phase.

Results

Training with Trial-Unique Wild Cards

Figure 8 shows how percentage correct for the color and shape lists and the RS–U lists (i.e., RS to WC and WC to U) varied as a function of training. Chloe's accuracy decreased slightly on both baseline no-WC and WC trials in the beginning of trial-unique wild-card training. Although there was a slight difference in accuracy on WC-first and WC-second trials for both color and shape pairs in the first phase, this difference almost disappeared by the end of the second phase.

Introduction of RS–WC and WC–U Pairs

Accuracy on WC-to-U trials was far above chance from the first two sessions (79.2%, see Figure 8), gradually improved over the second and third blocks, and then finally exceeded 90%. Chloe showed below-chance accuracy on the RS-to-WC trials during the first two sessions of its introduction (33.3%). Performance then quickly improved and exceeded 90% in the fifth session (third block). Performance on the other baseline pairs was not disrupted by the introduction of the RS-to-WC pair.

Training with Intermittent Reinforcement

During intermittent-reinforcement training, Chloe's performance was not disrupted by nonreinforcement. Mean accuracy across all sessions of this training (17 sessions) was 95.7% (±3.0% among the all pairs), almost the same as in the previous blocks (95.0% on average, ±3.7%).

Transfer Training with New Wild Cards

During transfer training with new wild cards, the introduction of new wild cards had no disruptive effect on performance; Chloe was correct on 98.6% of the trials without wild cards, 95.7% of the old CHN wild-card trials, 95.4% of the new CHN wild-card trials, and 90.3% of the kana wild-card trials averaged across all sessions (12 sessions) in this phase. Although we should consider the possibility of simple stimulus generalization from old to new wild cards, these results suggest that control by both stimuli in the pair might be established through the trial-unique wild-card training. Furthermore, omission of the 0.5-s feedback chime in the nonreinforcement trials did not interfere with performances on WC trials, unlike in Experiment 3; the difference in accuracy on transfer trials with new wild cards for the feedback versus nonfeedback conditions was only 0.7%.

Reversal Training

Figure 9 shows percentage correct for the first four sessions of reversal training. The results of two-session training with old wild cards immediately before reversal training and the last four sessions of reversal training

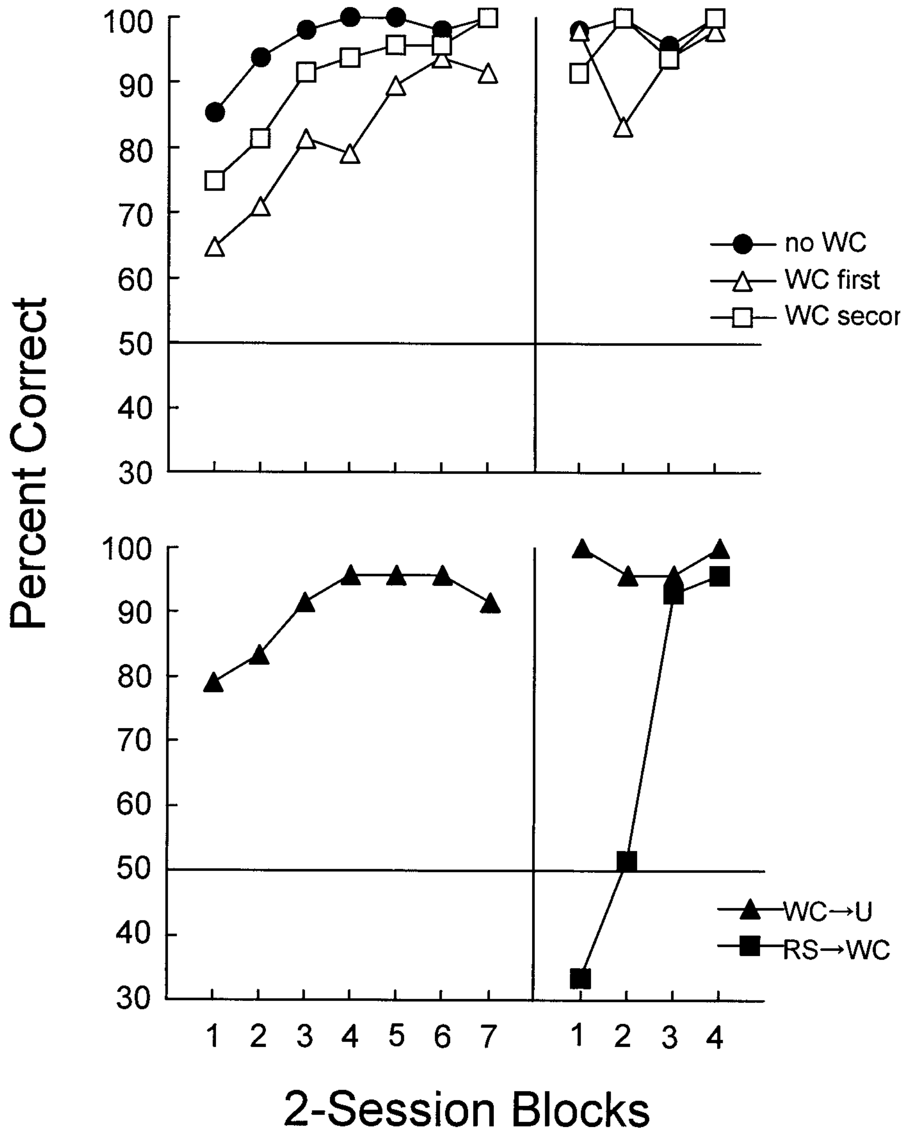

Fig. 8. Percentage correct for the color and shape pairs and RS–U pairs during the first two phases in Experiment 4. The data are plotted separately for the three types of lists (no WC, WC first, and WC second) as a function of two-session blocks.

are also shown in this figure. In the first session of reversal training, Chloe showed chance-level performance on all types of trials (mean percentage correct was 41.7%). Accuracy immediately improved in the second session showing 74.0% correct and was later maintained at the 90% level except for color–WC pairs (WC to green and red to WC) on which Chloe performed almost randomly with both pairs (56.2% correct averaged for the last four sessions).

Probe Tests for RS–U Pair

Table 6 shows the results of the RS–U probe trials in original and reversal training. The results of the baseline RS–U trials with wild cards are also shown in this table. Chloe consistently selected the RS first and the U

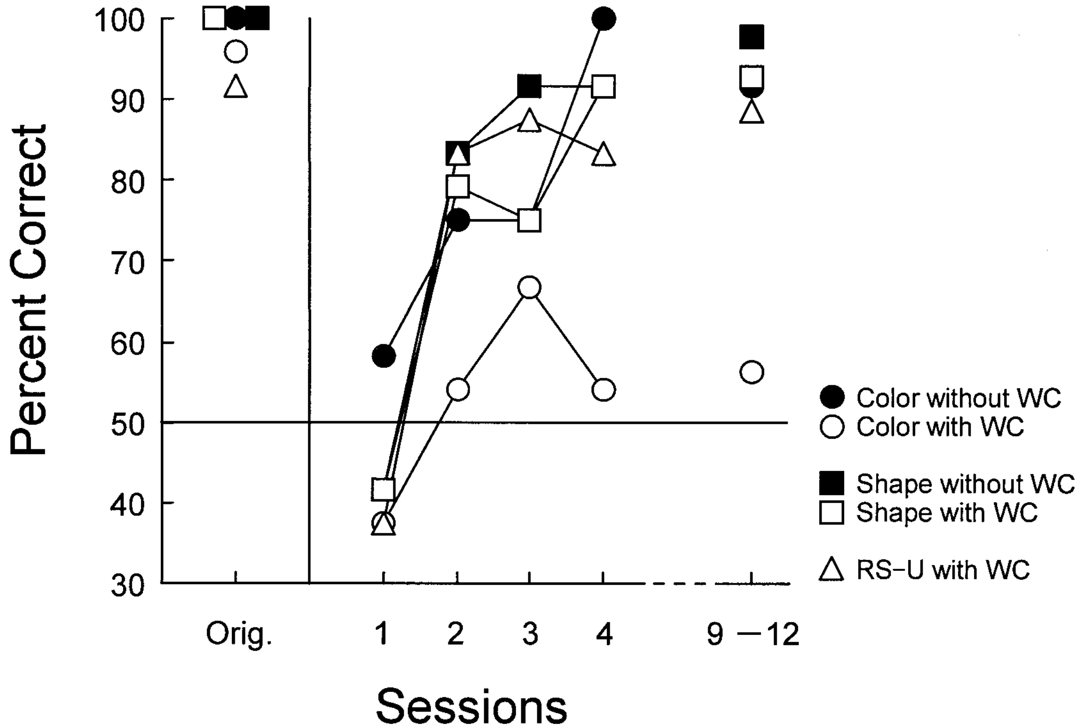

Fig. 9. Results from the first four sessions in the reversal training in Experiment 4. The data are plotted for the five types of lists. Mean accuracy across the two-session training with old wild cards immediately before the reversal training (Orig.) and that across the last four sessions of reversal training (9–12) are also shown.

second (91.7% correct, $p < .01$; binomial test) on the RS–U probe trials under the original-order contingency. She selected the U first and the RS second (91.7% correct, $p < .01$; binomial test) when she experienced the reversed order with the other pairs during reversal training.

DISCUSSION

The results of the present experiment offered some additional information about stimulus control of sequential responding, especially about control by the second stimuli. First, Chloe responded appropriately even when a trial-unique wild card was substituted for an item of the list. If her behavior had been controlled by a specific set of stimulus configurations, performance should have deteriorated in the wild-card trials. Furthermore, if performance had been controlled only by the first stimulus chosen, it should have worsened when a wild card was substituted for the first stimulus, as seen in the wild-card tests in Experiment 3. The fact that Chloe quickly learned both the WC-first and WC-second pairs, and that her performance remained at a highly accurate level during transfer training with new wild cards, suggest that control by both stimuli in the list might be established through the trial-unique wild-card training.

Second, Chloe's performance was not disrupted by nonreinforcement trials during intermittent-reinforcement training in which neither food reinforcers nor the other feedback stimuli followed responses, although the

Table 6

Percentage correct for baseline and probe trials during the initial and reversal training in Experiment 4.

		Order	
	Pairs	Original	Reversed
Baseline	RS–WC	91.0	79.2
	U–WC	96.5	82.6
Probe	RS–U	91.7*	91.7*

* $p < .01$, binomial test.

correction procedure was also in effect for these nonreinforcement trials in this phase. This result seems inconsistent with her probe performances in Experiment 3 (Table 3), for which she changed the response order after nonreinforcement probe trials on a significant number of trials. The results of Experiment 4 might suggest that Chloe's sequence reversal was not controlled by the absence of food or feedback in the previous trial.

Third, two new pairs that each contained one wild card (RS to WC and WC to U) were easily merged into one list, RS to U. Furthermore, even though this merged list performance was not explicitly reinforced, when the order contingency for the other lists was reversed, Chloe's response order significantly changed to U to RS. These results indicate a transfer of sequential responding to the new list, which was trained with wild cards in order to establish control by both stimuli separately.

Recently, McIlvane and his colleagues invented the *blank-comparison* procedure to establish stimulus control or stimulus classes effectively in the conditional discrimination format (McIlvane, Kledaras, Lowry, & Stoddard, 1992; McIlvane, Withstandley, & Stoddard, 1984; Serna, Dube, & McIlvane, 1997; Wilkinson & McIlvane, 1997). In this procedure, a neutral gray square (blank comparison) is substituted for a positive or negative comparison stimulus to assess and establish positive and negative stimulus relations. The present wild-card procedure is analogous to the blank-comparison procedure. Such procedures in which each of controlling relations was explicitly trained facilitates the establishment of control over discriminative behavior by appropriate stimuli (in the present case, control by both the first and second stimuli).

GENERAL DISCUSSION

The aim of the present study was to establish functional classes in sequential responding in a chimpanzee using a successive-reversal training procedure. In Experiment 1, performance on probe trials provided no strong evidence for the formation of functional classes with the between-session successive-reversal training procedure. In nonreinforcement probe trials, control by the original order established during initial training was consistently dominant in the shape pair but not in the color pair, for which the subject showed near-chance performance. Such an asymmetry of effects of successive-reversal training was also present in various tests in Experiment 3. Experiment 2 introduced within-session successive-reversal training. Contrary to Experiment 1, the performances on differential-reinforcement probe trials gradually improved as more reversals were presented. These results parallel those obtained from pigeons' simple successive discrimination by Vaughan (1988). Within-session successive-reversal training may have generated two functional classes. Successive-reversal training has been known to facilitate the formation of learning sets (Harlow, 1949; Schusterman, 1962). Schusterman used a single set of two stimuli in successive-reversal training in chimpanzees. In the present experiments, two sets of two-item lists were employed during successive-reversal training. In Experiment 2, the procedures used in the first two trials in a block were identical to the single-set successive-reversal training. Chloe's performance on the second trial was identical to that in a single-set successive-reversal training. On the third trial, Chloe was given a different pair from that which appeared in the first two trials. If functional classes had not been established, the response order in the previous trial block should still have controlled the subject's responding. However, as the reversals went on, her performances on the third trial gradually improved. Transfer occurred to the pair that was not trained in reversal.

Experiment 3 tested the control of sequential responding by functional classes. The results suggest the dominance of control by a stimulus to be responded to "first," not by the respond-second stimulus and not by both. Furthermore, it is suggested that the change in response order might simply have been controlled by the nondelivery of food reinforcement on the previous trial. Experiment 4, with trial-unique wild cards, however, offered evidence for control by both the first and second stimuli. The results from probe trials with the RS and the U showed that separate training of the first and second stimuli could transfer to the combined list RS–U. Furthermore, reversal of the order contingency for baseline pairs affected the response order of this combined pair on probe trials.

It should be noted, however, that performance on the RS–U probes could have been controlled by only one of the specific stimuli (e.g., ''given RS, respond to that one and then to any other stimulus''). This possibility should be examined under a testing paradigm different from the present one.

Experiments 3 and 4 offered interesting results. In sequential-responding studies with animals (D'Amato & Colombo, 1988, 1989, 1990; Straub & Terrace, 1981; Terrace, 1991), interest has focused on ''representations'' of linearly arranged stimuli, such as on chunking (Terrace, 1991), transitive inference (D'Amato & Colombo, 1988; Straub & Terrace, 1981; Tomonaga, Matsuzawa, & Itakura, 1993), and the symbolic distance effect (D'Amato & Colombo, 1991; Tomonaga et al., 1993). The nature of the controlling relations in simple sequential responding has not been a focus in such research. In the present experiments, two-item lists were used. In such lists, the subject might only have learned which stimulus she had to respond to ''first'' in the early phase of this study. The stimuli to be responded to second might have acquired no discriminative control over sequential responding (cf. Sigurdardottir et al., 1990). This situation may be similar to simple simultaneous discrimination. In animals, only the positive stimulus may acquire control of behavior in a simultaneous discrimination (Rapp, 1990). In the wild-card test in Experiment 3, when the first stimulus was replaced with a novel wild-card stimulus, Chloe performed almost randomly, whereas her sequential responding was maintained when the second stimulus was replaced with the wild card. These results suggest the possibility that sequential responding was controlled only by the stimuli to be responded to first. These types of stimulus control also seem to be parallel to control by positive stimulus relations in conditional discriminations (Carter & Werner, 1978; Cumming & Berryman, 1965).

If the second stimuli played little role in two-item lists, the subject actually might not have learned two functional classes *based on the ordinal positions*. As Sigurdardottir et al. (1990) suggested, ''the second stimuli might have been treated as a class simply because they were the ones that were left after a response had been made to the first member of each pair'' (p. 48). In the present experiments, because the role of stimuli was reversed successively, the possibility noted by Sigurdardottir et al. might be less likely. By applying the successive-reversal training procedure, two distinct functional classes might have been established. To assess the functional class formation on the basis of ordinal positions during sequential responding, however, lists with at least three items (usually five items) should be employed. For example, suppose that the orders A, B, to C and X, Y, to Z were reinforced in a given phase, and the former was changed to B, C, to A. If functional classes based on the ordinal positions had not been established, the subject would not be able to respond in the order Y, Z, to X in the latter list in successive-reversal training.

The other point to be noted is concerning the properties of ''ordinal'' classes. Green, Stromer, and Mackay (1993) suggest in their theoretical paper that ordinal stimulus classes are defined by the properties of transitivity, irreflexivity, asymmetry, and connectedness. These properties must be applicable not only to each item but to each ordinal ''class'' of items. Therefore, we should use several sets of longer lists (e.g., five-item lists) to assess these properties.

Strictly speaking, ''emergent'' stimulus control was not demonstrated in the present experiments. That is, the function of each stimulus at each point of testing had been explicitly established by reinforcement during the training. Only a spontaneous change from one trained order to another trained order was found. This was another procedural limitation of the successive-reversal training. One possible way to avoid this limitation would be to investigate the transfer of functions across different tasks (Hayes, 1991). For example, Lazar (1977) tested the transfer between sequential responding and matching to sample. De Rose et al. (1988) also tried to test the transfer between simple and conditional discriminations. Sidman et al. (1989) tried to establish functional classes by using successive reversal of simple discriminations and testing the transfer of function to matching-to-sample performance. We should also test whether functional classes established through successive-reversal training in the present experiments might transfer to other tasks.

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QUOTATION

I. P. Pavlov's Advice for Young Scientists

What would I wish for the young people of my motherland who dedicated themselves to science?

First of all—consistency. Of this very important condition for fruitful scientific work I cannot speak without emotion. Consistency, consistency and again consistency. Right from the very beginning inculcate in yourself the habit of strict consistency in acquiring knowledge.

Learn the ABC of science before you attempt to scale its peaks. Never embark on what comes after without having mastered what goes before. Never try to cover up the gaps in your knowledge, even by the boldest guesses and hypotheses. No matter how this bubble may delight the eye by its profusion of colours, it is bound to burst, and you will be left with nothing but confusion.

Develop in yourself restraint and patience. Never funk the hard jobs in science. Study, compare, accumulate facts.

No matter how perfect a bird's wing may be it could never make the bird airborne without the support of the air. Facts are the air of the scientist. Without them you will never be able to take off, without them your "theories" will be barren.

But when studying, experimenting and observing, do your best to get beneath the skin of the facts. Do not become hoarders of the facts. Try to penetrate into the secrets of their origin. Search persistently for the laws governing them.

The second thing is modesty. Never think that you know everything. No matter in what high esteem you are held always have the courage to say to yourself: "I am ignorant."

Do not let pride take possession of you. It will result in you being obstinate when you should be conciliatory. It will lead you to reject useful advice and friendly help. It will deprive you of the ability to be objective.

In the team of which I am leader, everything depends on the atmosphere. All of us are harnessed to a common cause and each pulls his weight. With us it is often impossible to discern what is "mine" and what is "yours," but our common cause only gains thereby.

The third thing is—passion. Remember, science requires your whole life. And even if you had two lives to give they would not be enough. Science demands of man the utmost effort and supreme passion. Be passionate in your work and in your quests.

Our country is opening wide vistas before scientists, and—it must be owned—science in our country is being fostered with a generous hand.

What is there to say about the status of our young scientist? Here, it would seem, everything is quite clear. Much is given to him, much is expected from him. For him, as for us, it is a matter of honour to justify the great trust that our country puts in science.

From: *I. P. Pavlov: Selected works.* Moscow: Foreign Languages Publishing House, 1955, pp. 54–55. This year marks the author's 150th birthday; he was born on September 26, 1849, and died on February 27, 1936.

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